Programmable Logic Controllers:

An Emphasis on Design and Application

Fourth Edition

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Dedicated to Fran, Esther, David, Amanda,
Ezra, and Elijah

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PREFACE

The field of automatic control has been undergoing a transformation over the past forty years. Forty years ago, the engineering undergraduate had a course in feedback control theory and those interested in control engineering secured a position in the aerospace or chemical industries. Due to various factors, the number of control engineering positions in the aerospace industry has declined, but the number of control engineering positions in manufacturing has dramatically increased so that the majority of control engineering positions is now in manufacturing and involves PLCs.

This book presents the subject of programming industrial controllers, called programmable logic controllers (PLCs) with an emphasis on the design of the programs. Many texts teach one how to program the PLC in its languages, but little, if any, attention is paid to how does one attack the problem: "Given a set of operational specifications, how does one develop the PLC program?" This book develops the design process: the tasks involved, breaking the program into manageable pieces, standard code for the various parts, and handling the sequential parts of the problem. The emphasis is toward those who will be programming PLCs.

Because of its popularity, ladder logic is the language that is used for the majority of the text. The industry trend is toward using the IEC 61131-3 (formerly IEC 1131-3) standard, and so it is an important language. However, IEC 61131-3 is only a voluntary standard and individual manufacturers have some freedom in the implementation. Therefore, the Rockwell ControlLogix, Siemens S7, Modicon M340/M580 and Emerson implementations of the 61131-3 standard are covered. Because of their large installed base, the Rockwell MicroLogix/SLC-500 PLC languages are also covered.

Due to the limitations of ladder logic, the IEC 61131-3 standard defines four other languages: function block diagram, structured text, instruction list, and sequential function chart. All but the instruction list language are becoming popular. Therefore, this text also covers these four languages.

Since a typical manufacturing plant may contain discrete, continuous, and batch processes, all of these applications are treated in this text, although the emphasis is on discrete and continuous processes. The emphasis is on a methodology that can be applied to any automation project, regardless of the size.

Throughout, the book contains example problems demonstrating good design practice. In addition, these problems are solved with each PLC covered in the book. The text culminates in two full-length case studies where the application of the design techniques to a large problem is illustrated.

This book takes a practical approach to the design of PLC control systems. Some mathematical theory is used to backup the presentation on PID controllers. However, the theory is not detailed and can be omitted.

Except for Chapters 1 and 13, every chapter begins with a scenario that reflects the experience of the author and his colleagues in the challenging world of factory automation.

These scenarios present a small problem and the solution and are intended to illustrate troubleshooting techniques.

Objectives

The main objectives of this text are to teach:

- PLC programming languages (with emphasis on ladder logic)
- Approach to sequential problems
- Good program design practice
- Simple PID control tuning
- Introduction to sensors and actuators
- Factory communications
- Human-machine interface (HMI) concepts

Content Overview

The book starts by introducing programmable logic controllers (PLCs) and their distinguishing characteristics. Chapters 2 – 5 cover basic ladder logic programming: contact, timer, and counter instructions. As part of the basics, the memory structure of the five particular PLCs and installation topics are treated. Chapter 6 covers ladder logic program design for sequential applications, probably the most significant contribution of the text. Chapters 7 and 8 treat computation, comparison, and advanced ladder logic instructions. Alternate sequential implementations in ladder logic are covered in Chapter 9 and PID controller tuning is covered in Chapter 10. Chapters 11 – 14 cover the other four IEC programming languages: function block diagram, statement list, instruction list, and sequential function chart. PLC troubleshooting is covered in Chapter 15. Sensors and actuators appear in Chapter 16. Chapter 17 introduces factory communication networks. Operator interface, often called human-machine interface (HMI), issues are treated in Chapter 18. Control system security is addressed in Chapter 19 and PLC selection is introduced in Chapter 20. Chapter 21 presents the perspective of an entire automation project, bringing together the various pieces of PLC control design. Chapter 22 outlines two full-length project case studies. One case study is for a process that is primarily discrete and the other case study is for a process that is primarily batch and continuous in nature. Details about number systems and drawing symbols are included as appendices, rather than interrupt the flow of the text material.

The Audience

This book primarily serves the academic market, at the junior or senior undergraduate electrical, mechanical, or industrial engineering or engineering technology level. This text is also suitable for the two-year technical school market. There is nothing in the material that requires a college degree, though the material will be more challenging than the typical PLC textbook for this level of student.

In addition, this text serves the professional market. Economic and regulatory pressures in the manufacturing, chemical, petrochemical, pharmaceutical, and food industries have forced control engineers to design new systems or retrofit existing control

systems. Hence, there are many control engineers (primarily chemical, electrical, and mechanical) who need to rapidly educate themselves in an area of technology in which they are probably only somewhat familiar. This book is valuable to this audience.

Online Content

Supplementary online content for the text is posted at **www.dogwoodvalleypress.com** and includes:

1. PLC project files and print-outs for the text examples.
2. Additional problems with solutions.
3. PID tuning demonstrator program.
4. Design documentation for the coal handler project in Chapter 22.
5. Preliminary design information for the multi-unit chemical process in Chapter 22. This is a set of design information and standards for the process, intended to be used for a classwide control system project. There are no mechanical or electrical drawings.

Fourth Edition

The fourth edition primarily updates the Rockwell, Siemens, and former GE processors, but there are other changes throughout. In 2019, Emerson Electric Co. purchased the Intelligent Platforms division from General Electric. So, the former GE PLCs are now branded as Emerson PLCs. Only the PACSystems and VersaMax processors are currently available. The appearance of the ControlLogix blocks is changed to match the modifications introduced in Logix Designer revision 31. Addressing for 5069- and 5094-series I/O modules has been added to Chapter 3 and new ControlLogix blocks related to process control have been added to Chapter 10. The Siemens S7-1500 CALCULATE block, introduced in version 14, has been added to Chapter 7. An implementation of the S7-300/400 FIFO/LIFO blocks that were not ported to the S7-1500 are described in Chapter 8 and implemented in the SCL language in Chapter 12. New S7-1500 blocks for process control are described in Chapter 10. Information on input and output buffering has been added to Chapter 2. In Chapter 9, the move-based implementation of sequential operations is added and the section on sequencer blocks is removed. A structured text implementation of sequential operations is added to Chapter 12. The Chapter 16 problems and the appendix with the thermocouple conversion polynomial coefficients have been deleted. In Chapter 17, the WorldFIP network has been removed. Chapter 19 is updated for changes in the security features of the processors. The implementation of sequential operations in Chapter 21 is changed to the move-based sequencer. In addition, simulation of the process with the ControlLogix and S7-1500 processors is changed to add (and emphasize) module inhibits. The multi-unit chemical process in Chapter 22 is now larger. Lastly, all of the chapter problems have been replaced with new problems.

Throughout the text, ControlLogix refers to both the ControlLogix and CompactLogix controllers, unless noted otherwise. Similarly, S7 refers to S7-200, S7-300, S7-400, S7-1200, and S7-1500 processors. The wording “Step7 Portal” refers to the S7-300/400/1200/1500 processors programmed with the Step7 Portal software and “Step7 Classic” refers to the S7-300/400 processors programmed with the Step7 Classic software. The Modicon material features the M340 and M580 processors programmed with

EcoStruxure Control Expert software. The material on Emerson processors favors the PACSystem processors, though VersaMax processors are also covered.

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